IMPACTS OF CLIMATE CHANGE ON UTILITY VEGETATION MANAGEMENT IN FLORIDA

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Executive Summary

Richard Morton has several years of experience in the vegetation management division of Florida Power and Light and has seen firsthand some of the challenges facing the infrastructure. Numerous strong storms have demonstrated that vegetation can be the cause of significant power outages across the state and that even during periods of calmer weather they can still have impacts on day to day operations. With ever growing concerns about climate change and its impacts, it was time to take a look at what kind of role it might play on the number of vegetation caused outages across the state of Florida. Vegetation falling on power lines and equipment is one of the leading causes of outages, which negatively impacts a utility's customers and can be costly. This Capstone Project through the Energy Policy and Climate program at Johns Hopkins looks directly at that issue since there has been very little previous research done on the subject. The aim of this project is to determine if there is a link between climate change and the number of vegetation caused power outages, which would at least start a discussion on what steps might need to be taken to mitigate the impacts if a clear link is found. The basis for this study comes from previous research which has shown how climate change will impact forest growth. With longer growing seasons and changes in perception levels, trees will be able to grow for longer periods of times. It will also cause other species to migrate north, and cause die-offs of non-suitable species. Variability in weather patterns can lead to more extreme events, which will also impact the health of a tree. Each of these factors can leave a tree in danger of causing a power outage. In order to determine if there is any link between climate change and the number of vegetation caused outages, yearly average temperatures, wind speeds, and rainfall totals were gathered for the entire state of Florida along with a breakdown of the total number of vegetation caused outages for each of the publicly owned utilities across the state. Analysis was done to

look for any correlation amongst the variables and to determine if any of them appeared to play a role in the number of outages. Ultimately, due to the way the outages are reported to the state, there was inconclusive evidence to determine if there is a link. This does not mean the project was a failure, and instead valuable information was gained on what data would be needed to successfully retest the hypothesis in a future study. The information gained as a result of the inconclusive evidence demonstrates some of the issues with the data reporting that need to be resolved, including better access to spatial data to the public. While utilities should already have this data available, it would only be viable for their territory instead of a larger scope investigation that this study entails. In regard to demonstrating a wide-reaching phenomenon, the better reporting would allow for researchers to show that there may be a link between climate change and the number of vegetation caused power outages through the showing of patterns between the different utilities.

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Introduction

Society today is highly dependent on the use of electricity. When outages occur, they can cause severe disruptions to our daily lives, can cost over $100 billion per year (LaCommare & Eto, 2006) and can be a matter of life and death for some of the more vulnerable members of our community (Mitsova et al, 2018). Minimizing the amount of blackout time is a key goal for any electric utility, and fines can be imposed under some circumstances for those outages. Unfortunately, power outages are still frequent enough that the average American will spends around four hours each year without electricity due to an outage (EIA, 2018). The top two causes of power outages in the United States are from storms and vegetation (Edison Electric Institute, 2016; FERC, 2018). Storm related outages occur due to events such strong winds, extreme precipitation, and lightning. Vegetation caused outages are defined by trees or vines contacting the electrical lines or other power equipment. Often, these two are related. High winds can knock branches or trees into power lines. Extreme rainfall events lead to soil saturation which can uproot trees. Extreme heat combined with dry conditions weaken limbs which when they come in contact power lines, can spark large fires such as the ones seen in California (CAL Fire, 2019). All of these conditions also play a role in tree growth rates, which can cause them to speed up or slow down depending on the species and their individual climatic needs. Since electric utilities maintain their lines on multi-year cycles, changes in these growth rates, especially if they increase, can threaten facilities at an accelerated rate.

The aim of this project is to look into a potential relationship between the number of vegetation caused power outages and the current trends in temperature, rainfall, and wind speed that are being driven by climate change as there currently is very little on the subject. There is already established information on how forest ecology will change in the face of climate change, but none that focus on the impact of vegetation along a utilities right-of-way, and its overall reliability. Determining if there is a relationship is important, as this would allow for utilities to better mitigate the impacts of climate change on their system, while simultaneously increasing the reliability of the grid. By ignoring any potential relationship, a utility risks decreasing its reliability, causes a loss of income, increases the amount of maintenance work, and opens up the utility to potential fines.

This study will focus on the state of Florida, which was the only known state to have published publicly available data on the total number of vegetation caused outages. The published data comes from each of the publicly owned power utilities in the state, which are Duke Energy (Duke), Florida Power and Light (FPL), Florida Public Utilities Company (FPUC), Gulf Energy [1](Gulf), and Tampa Electric Company (TECO). It is predicted to find that there will be a positive correlation between the number of vegetation caused power outages and temperature, rainfall, and wind speed increases. This is based upon the already established prior research into forest ecology and how changes in the weather play into tree growth, which is explored in the next section. In order to test this hypothesis, a statistical analysis will be done that looks at current trends of all the variables, and changes in the standard deviation to indicate if climate variability is playing a role. The data will then be further broken down by each utility's service territory to determine if there are any patterns in the data that would also continue to support the idea that climate change is playing a role in the number of vegetation caused power outages.

[1] Gulf Energy was purchased by NextEra Energy in 2018 and merged with Florida Power and Light in 2019 so the data collected from Gulf Energy will remain separated from Florida Power and Light since this project only relies on data through the end of 2018.

Literature Review

The basis of this study comes from previous research into the impacts of climate change on forest ecology. Kirschbaum et al. (1996) noted that “climate has significant influence on the distribution, structure, and ecology of forests”. There are many ways in which climate change can impact forests in general. Factors such temperature and rainfall can greatly alter the growth rates of many different species (Parent et al, 2019). Temperature changes can also change the distribution of species that can exist in a community (Aitken et al., 2008). Certain species adapted to cooler climates will die out, and species adapted to a warmer climate will take their place (Ashraf et al, 2015). Excessively high temperatures reduce a trees ability to respire, which can result in a tree dying (Schippers et al., 2015). Warmer temperatures typically increase the growing season (CCSP, 2008). When it comes to rainfall, the amount a tree receives also plays a vital role in its growth rate (Morales et al, 2004). A lack of rainfall can kill a tree. Since climate change will alter rainfall patters, trees in various areas will start experiencing too much, too little, or wild swings in rainfall from year to year. Drier conditions can cause a tree to be more susceptible to wildfires due to a lack of moisture inside the tree (Stephens et al, 2018). Increases in precipitation levels also have negative effects on trees. Too much rainfall leads to flooding, which limits the ability of a tree’s roots to take in oxygen from the surrounding soil which effectively suffocates the tree (CCSP, 2008). Flooding itself can also lead to soil erosion which can then cause a tree to become uprooted and fall over. In addition, these changes can also weaken a tree’s ability to defend itself from disease, fungus, and pests which can continue to further weaken the overall structure of the tree (CCSP, 2008). Wind speeds are an important factor to look at in the terms of this project due to the role they can play in causing branches to detach from the tree or increasing the risk of a tree becoming uprooted. Interestingly, as the climate warms, average wind speeds may increase closer to the poles and decrease closer to the equator due to changes in storm tracks (McInnes et al., 2011). This matters since changes in storm patterns, in which windy conditions are expected, would also play a role in vegetation impacting power lines. However, it would be extremely difficult, if not impossible, to measure maximum wind speeds at the site of an outage, so for these averages for the entire year will be taken into account to determine if there are any long term patterns that might be of interest.

The science of climate change is already established. We are aware that temperatures are trending warmer and that rainfall patterns will be altered globally. While these are certainly important factors that need to be looked at, the other concern is going to be climate variability (Katz & Brown, 1992). Changes in storm severity and frequency can also severely damage trees due to temperature swings, changes in precipitation levels, and high wind speeds (Parent et al, 2019). These changes also greatly influence a tree's ability to adapt to further changes, which in turn increases the chances of a tree dying (Savolainen et al., 2007). A sudden and prolonged cold spell in Florida due to changes in the jet stream (Le Page, 2011) would harm trees use to the typically warm climate, and a prolonged drought in the summer months would cause trees to have to do without their usually daily rain showers. What kind of climate will Florida likely face in the future? Florida is likely to experience more frequent and intense heat waves (Cloutier-Brisbee et al., 2019) which increases the chance of drought events. Temperatures have already risen by one degree Fahrenheit over the past century on average across the state and are projected to continue to rise (EPA, 2016). The further south one goes in the state, the higher the temperature averages have warmed (EPA, 2016). Simultaneously, heavy precipitation events such as severe thunderstorms are also likely to become more frequent and intense (Cloutier-Brisbee et al., 2019), placing a greater risk on high wind events that can threaten the structure of a tree. Rainfall totals have been increasing by about 10% over the past century (FSU, 2008), and are expected to continue to rise. All of these changes to the climate will impact both individual trees and forests as a whole. Forest types will change as patterns switch, leading to the introduction of new species in regions as seen in image 1. Climate change is projected to make the various stressors that already impacts forests in Florida worse (McNulty et al, 2013).

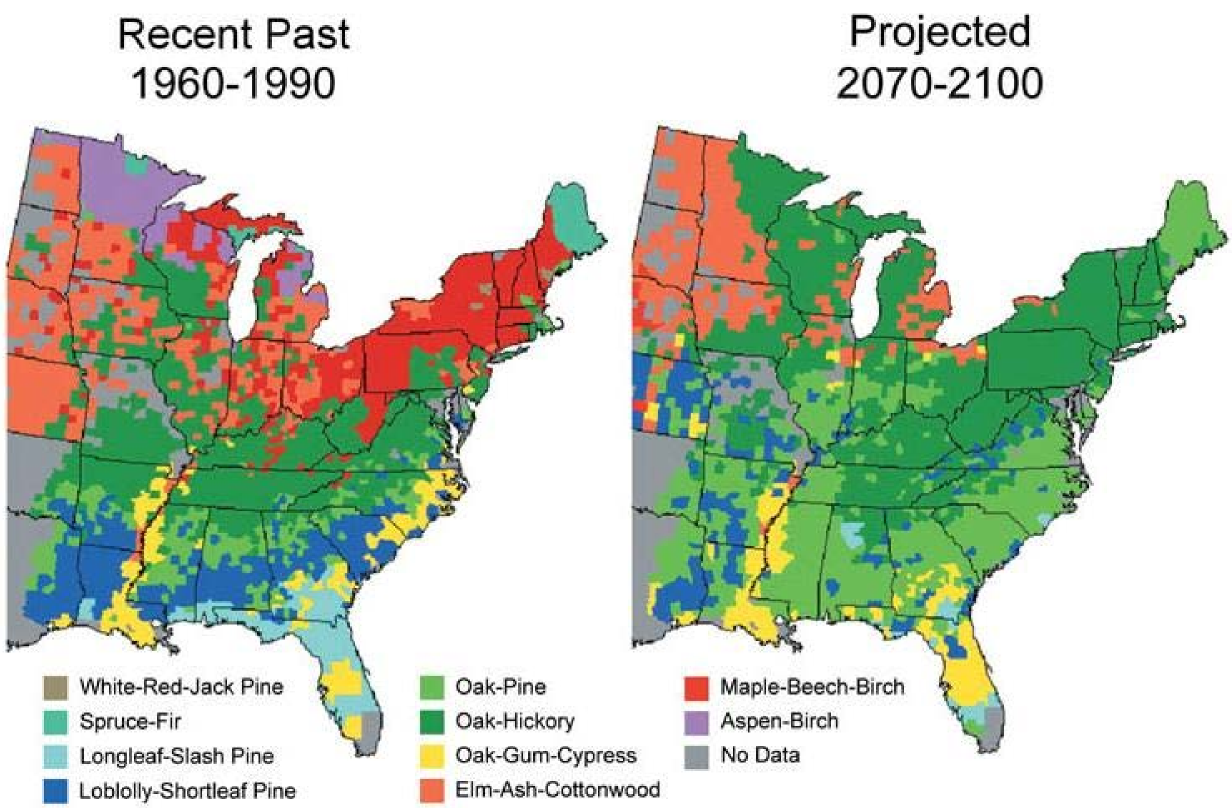

Image 1: Projected shifts in forests types. Source: USGRCP (2009)

In Florida, the main forest type will switch from being made up of long-leaf slash pines to oak-gum-cypress forests. Long-leaf slash pine forests are fast growing, with trees expecting to grow upwards to two feet per on average (Bennett, 1963). Oak-Gum-Cypress forests are a little more complicated since they are comprised by a number of different species[2], but on average are

[2] The following species can make up an oak-gum-cypress forest according to Virginia Tech*: Quercus michauxii, Quercus pagoda, Quercus texana, Quercus phellos, Quercus lytra, Liquidembar styaciflua, Carya aquatic,*

generally slower growing that long-leaf slash pines. However, climate change will impact these growth rates as noted earlier. The warmer temperatures will allow for a longer growing season. Increasing levels of CO_2 will allow for an increased rate of photosynthesis, which can in turn allow for both larger trees and forests (McMahon et al., 2010).

What does this mean for utilities? It means several things. First, we have seen that it is projected by the USGRCP (2009) that the primary forest type will change. This means new species with different growth rates will be growing in a utilities right-of-way. Second, temperatures are rising, rainfall totals are increasing, and severe thunderstorms are likely to become more frequent and intense. (Cloutier-Brisbee et al., 2019; FSU, 2008). This allows for a longer growing season and more opportunities for severe weather events to weaken a tree, also providing a hazard to electrical lines. Finally, stronger swings from the average in these variables will also weaken a tree, which once again, provides a hazard to electrical lines. Utilities need to be aware of the potential threats to their facilities that way they can attempt to mitigate the potential impacts. Failure to do so can mean decrease reliability and revenue and increases in expenses due to repairs. By determining and providing a warning, utilities can begin to put forth plans to reduce future impacts. This can range from expanding vegetation removal budgets, increasing the distance trees need to be from power lines, or placing the lines underground. An early warning gives plenty of time for utilities to adjust their budget accordingly and prevent the change in impacts from happening in the first place.

This study looks at data from 1997 through 2018 to determine if there is any long-term pattern between temperature, rainfall totals, and average wind speeds across the state to see if there are

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Chamaecyparis thyoides, Taxodium distichum, Nyssa aquatic, Magnolia Virginian, Nyssa biflora, and *Acer rubrum.* Growth rates differ from species to species, making it difficult to determine the overall growth rate of the forest.

any trends to indicate that there may be a rise in the number of vegetation caused power outages due to climate change. Research suggests that changes in these variables should lead to an increase in the number of outages. Data on the climate variability at a monthly scale would provide more insight and potentially yield better results, however due to the way that the data is reported to the Florida Public Service Commission, only yearly averages and variability are being considered. Data limitations are further explored in the discussion section. Instead, the data included will be the total number of reported vegetation-caused power outages as determined by the utilities, along with yearly average temperatures, rainfall totals, and wind speeds for each county across the state. This is done in effort to create a snapshot of the conditions that each utility faces, and if there are any common patterns found in each of the utilities territory since they cover different regions of the state (Image 2). Based off prior research into climate change and forests, it is projected to find that due to warmer temperatures and increased rainfall as a result of climate change, there will some correlation that indicates that long-term climate change is playing a role in the number of vegetation caused power outages. Warmer temperatures would provide longer growing seasons which would in turn allow a tree limb to potentially impact an electrical line before being trimmed on a normal maintenance cycle. Wind speed averages are unlikely to yield conclusive results since trees are more sensitive to high wind events, but still warrants an investigation.

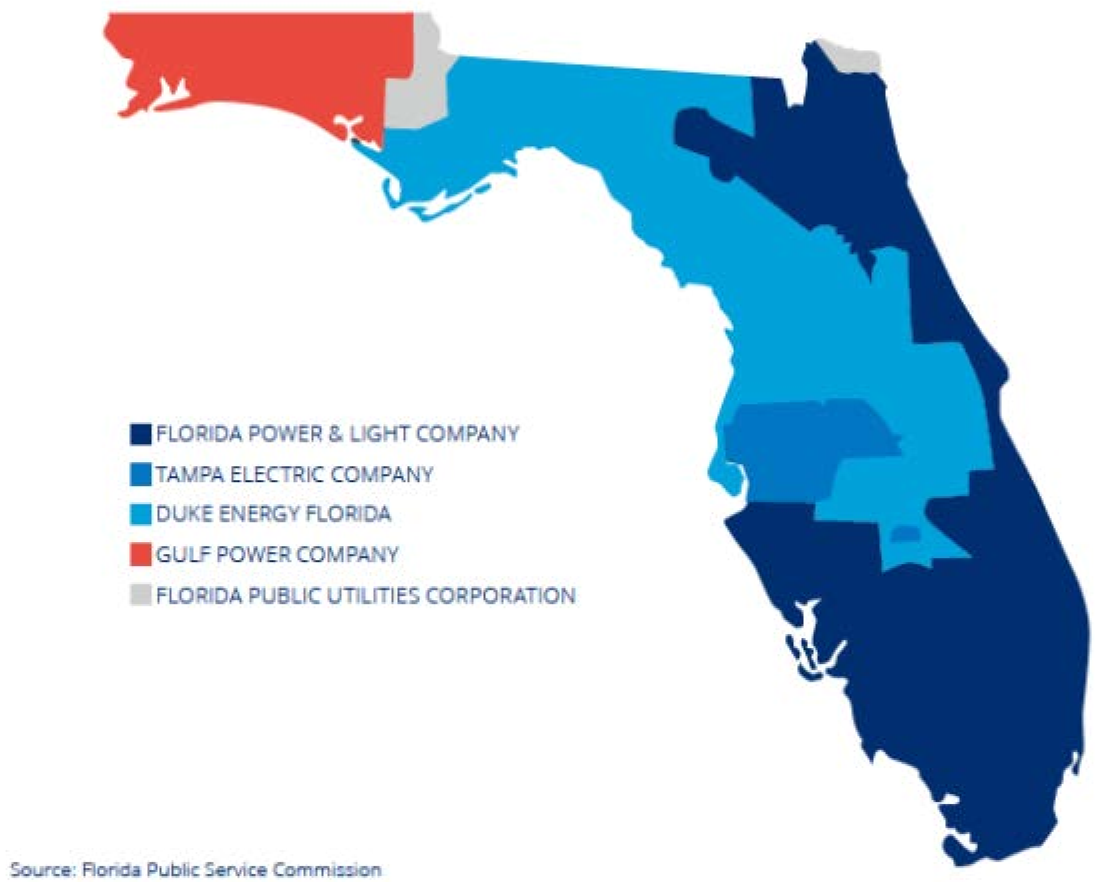


Image 2: Investor-Owned Electric Utilities Source: Florida Public Service Commission

Methods

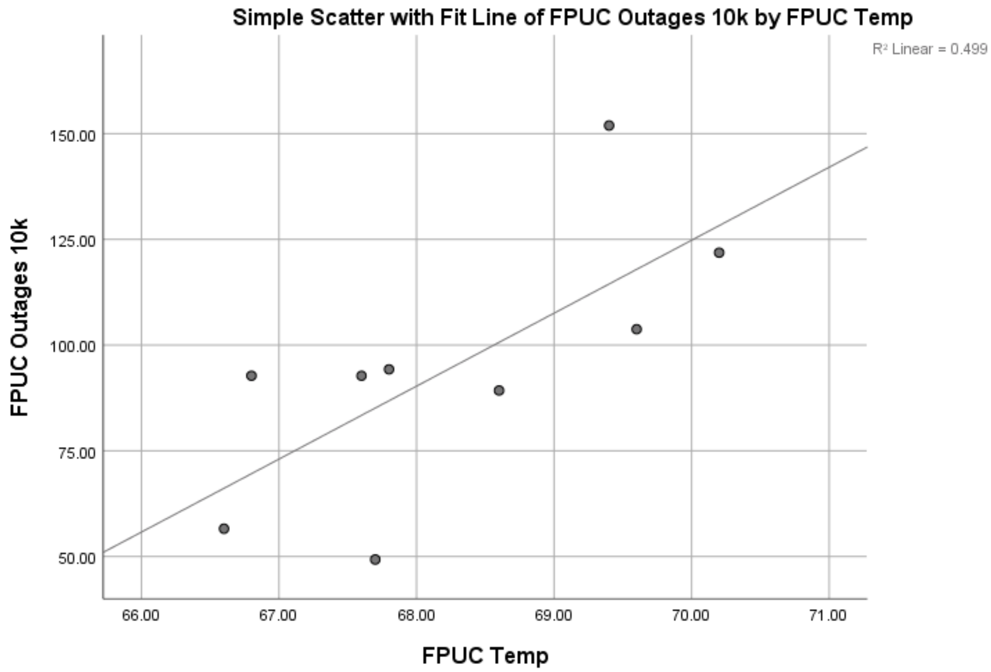
All data from this project came from publicly available resources. Data for temperature, rainfall, and wind speed all came from the National Climatic Data Center (NCDC). For each county in the state of Florida, the data chosen came from the most complete data list provided by the NCDC if there were multiple reporting stations. The data collected from the NCDC was the yearly average temperature, which was a collection of each of the hourly readings averaged for the entire year. Rainfall totals are simply the total amount of rainfall at the observation location. Wind speeds were also an average of hourly recordings throughout the year. For temperature and wind speeds, the data provided was a yearly average of the hourly recordings, with the individual hourly recordings being omitted themselves in the data package. Several Florida counties were removed from the data list. These counties were only removed due to the fact that they had not yearly weather data recorded, which would not yield any results. This should not have any impact on the overall results.

The data for the number of reported outages came from the Florida Public Service Commission (FPSC). The data came from required yearly reports on electric distribution reliability that are publicly available on the FPSC website. These reports include a breakdown of the total number of outages and the identified source of these outages. Vegetation caused outages include both trees and vine growth. The data listed only yearly totals for each utility, with no further breakdown of the data reported. An important note about the outage data is that the data reported to the FPSC was taken at face value. Each utility might have a slightly different method into determining what was coded as a vegetation-related outage and what is not, which could lead to some errors in the data. However, since it would be impossible to go back and verify each outage, the number reported to the FPSC will be taken as an accurate count for this research. Each utility reported on their own results based on their collection procedures. Data was then compiled at the end of the year and sent as a generated reported to the FPSC in accordance to the FPSC's rules and regulations. Utilities should have a more complete data set available, however none were available for this research.

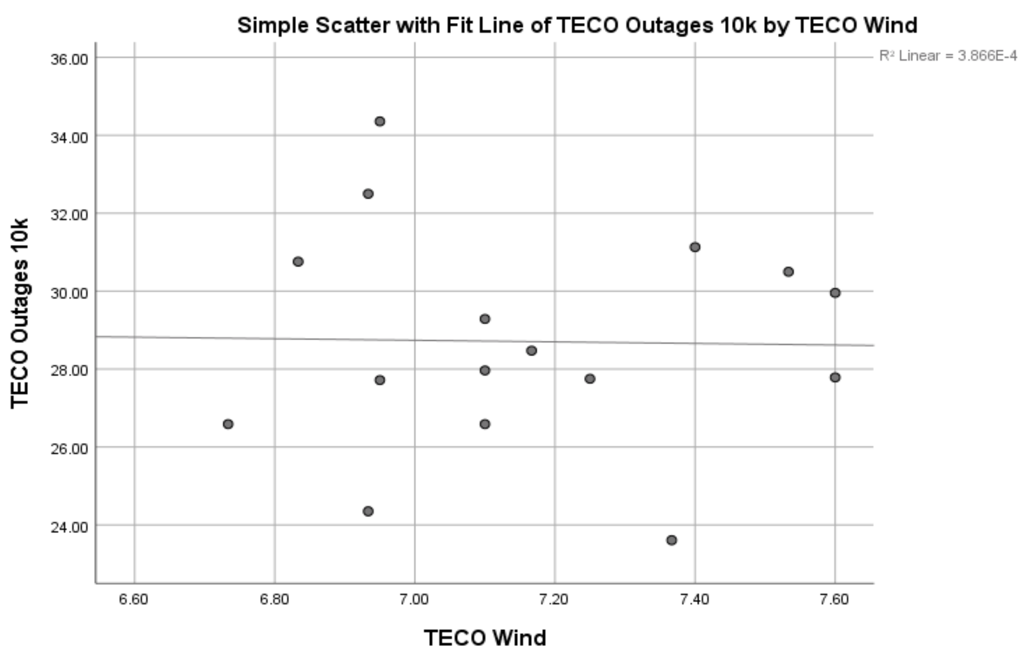
The data for both weather and the number of outages was collected from the start of 1997 through the end of 2018 as that was the greatest extent of data that the FPSC had on the number of outages. Each of the utilities territory as of the end of 2018 was looked at, and any county that was covered by said utility was flagged to indicate that service was provided. This is in order to provide weather data for any potential location there might have been a reported vegetation-caused outage covered within each utility's territory. As the data reported to the FPSC only indicates the total number of outages across each utility's territory, all weather data was averaged across each utility's territory and for the entire state.

Each utility is vastly different in size. Each one has continued to expand in size since the start of vegetation-caused outage data reporting in 1997. In order to reduce the effect that utility expansion and customer count has on the data, the number of outages per 10,000 customers was calculated. 10,000 was chosen as the baseline since the smallest utility has less than 30,000 customers (FPUC).

To begin the analysis, yearly average temperature, rainfall totals, and wind speed was graphed (graphs 4, 5 & 6) to indicate what kind of trend might be happening across the state and each of the utilities in terms of climate. This was done graphically through Excel. The standard deviation for the variables temperature, rain, and wind speed was taken for each year for the entire state to get a measure on climate variability throughout the testing time frame. Scatter plots comparing outages to each of the variables were then used to determine if trends were monotonic, linear, or non-monotonic. Results from this test indicated that, with the exception of the TECO wind and outages and FPUC outages and wind which exhibited a non-monotonic relationship, the other results yielded a monotonic and linear relationships. Two examples can be seen in graphs 1 and 2 below.



Graph 1 Example of one of the linear relationships between outages and temperature

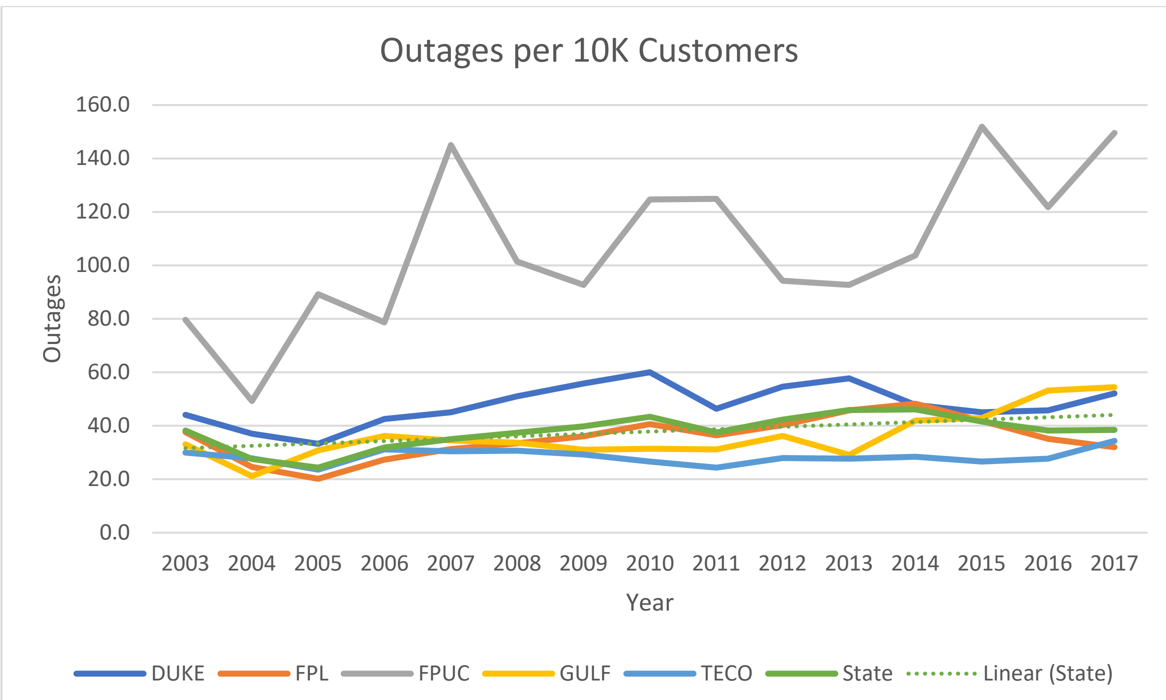


Graph 2 Example of one of the non-linear relationships as y is effectively zero.

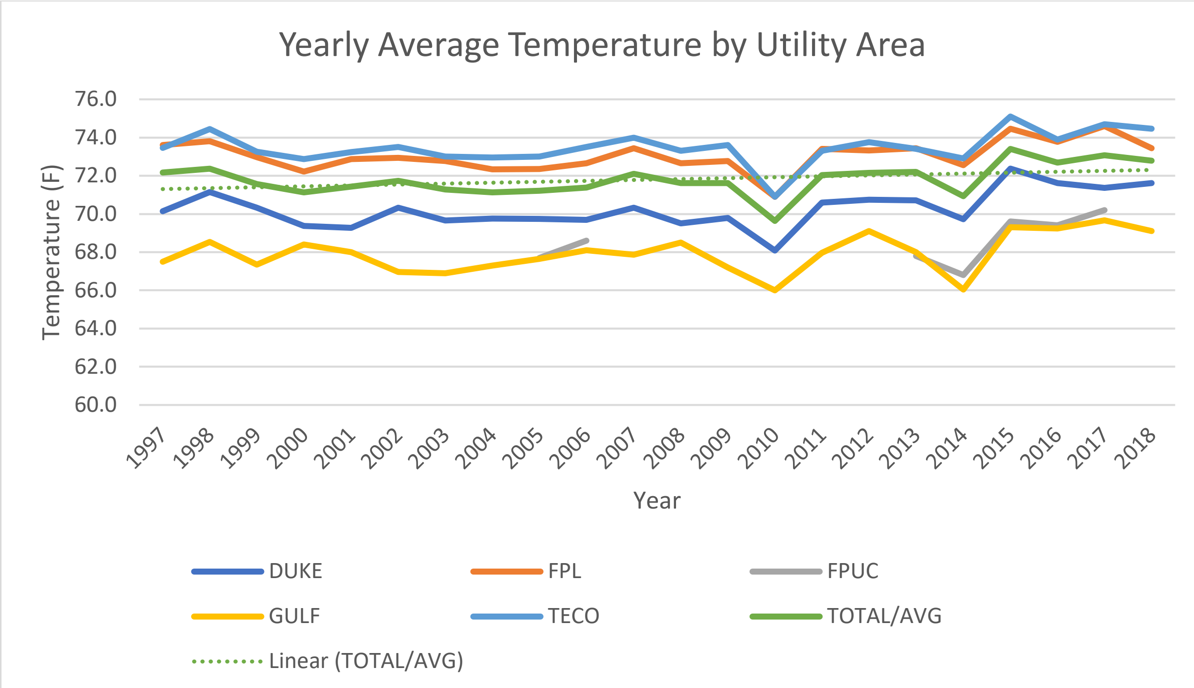
Since all the others exhibited signs of a linear-monotonic relationship, and there was no indication of any significant data outliers, a Pearson's Correlation test was ran on the data through the use of SPSS. This is in effort to determine if the variables average temperature, rainfall totals, and average wind speed are even related to the number of outages. The Pearson's Correlation test was one tailed as the hypothesis is looking for a potential increase in the number of outages as a result of the variables. Since climate variability is a major concern when it comes to climate change, Pearson's correlation was used again to look at standard deviation amongst the variables and compared to the number of outages. Standard deviation was calculated by taking each variable and getting the standard deviation amongst the five utilities for each year. For example, for the year 1997, the average temperature was taken amongst the utilities and from there a standard deviation calculation was performed. The goal of this test was to determine if increases in the number of outages could be correlated to larger variability in temperature, rainfall, and wind speeds. Large standard deviations followed by a statistically significant increase in the number of outages per 10,000 customers would indicate that the variability from the climate is playing a role in the number of vegetation caused outages as indicated by prior research. Since after this point results were indicating statistically insignificant findings, further analysis was halted. If results had come back statistically significant, a time series analysis would have been performed to predict what future numbers might appear to be if current maintenance practices remained. A regression test was then preformed on the data with state outages per 10,000 customers being the dependent variable, and temperature, rainfall, and wind speed each being independent variables. This was in order to determine if there is any collinearity among the variables.

Results

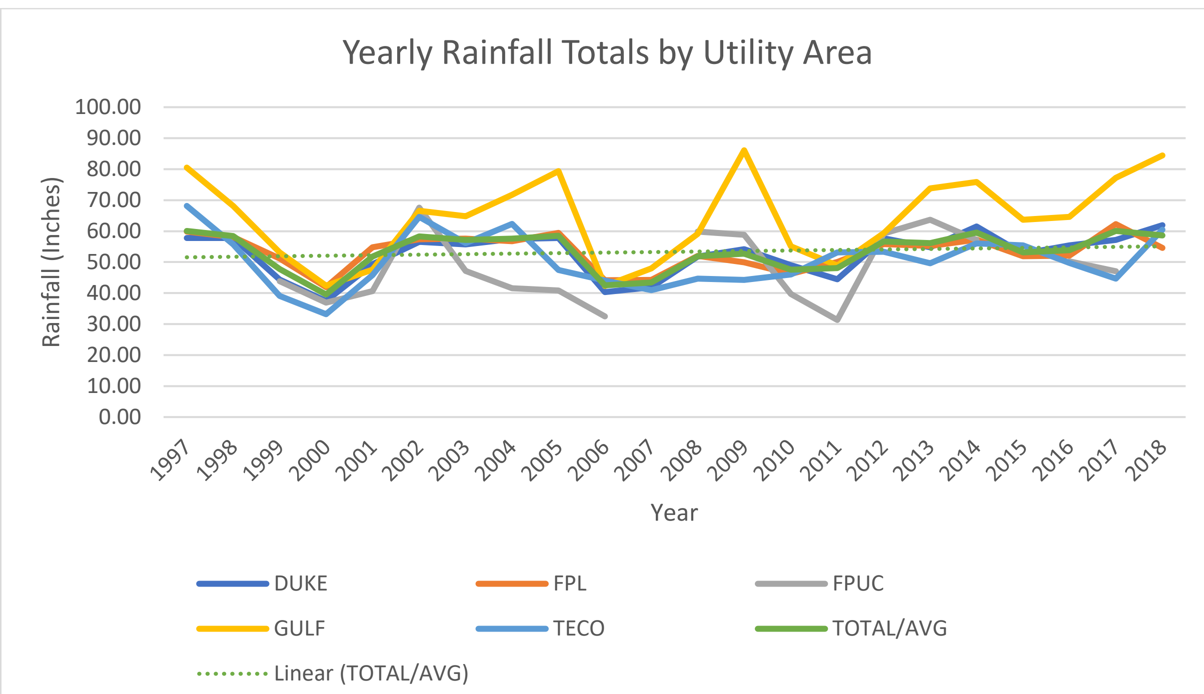
Graph 3 below indicates the number of outages per 10,000 customers by year and utility along with a state trend. Graph 4 shows yearly average temperature recorded throughout each utility's territory by year. Graph 5 shows the yearly rainfall totals averaged out through each utility's area. Graph 6 shows the average recorded wind speed averaged throughout each utility's area. These graphs represent historic data and what the current trends reflect.



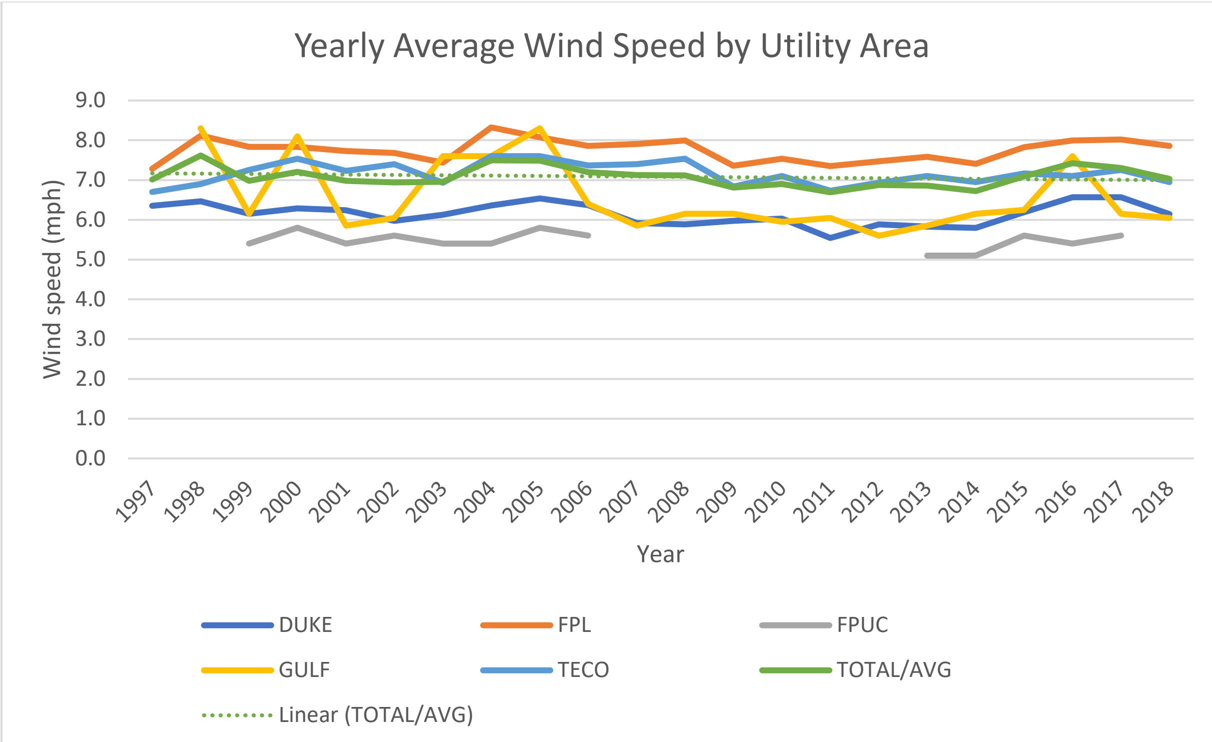
Graph 3 Outages per 10K Customers. Each line represents the respective utility.



Graph 4 Yearly Average Temperature. Each line represents the respective utility average temperature.

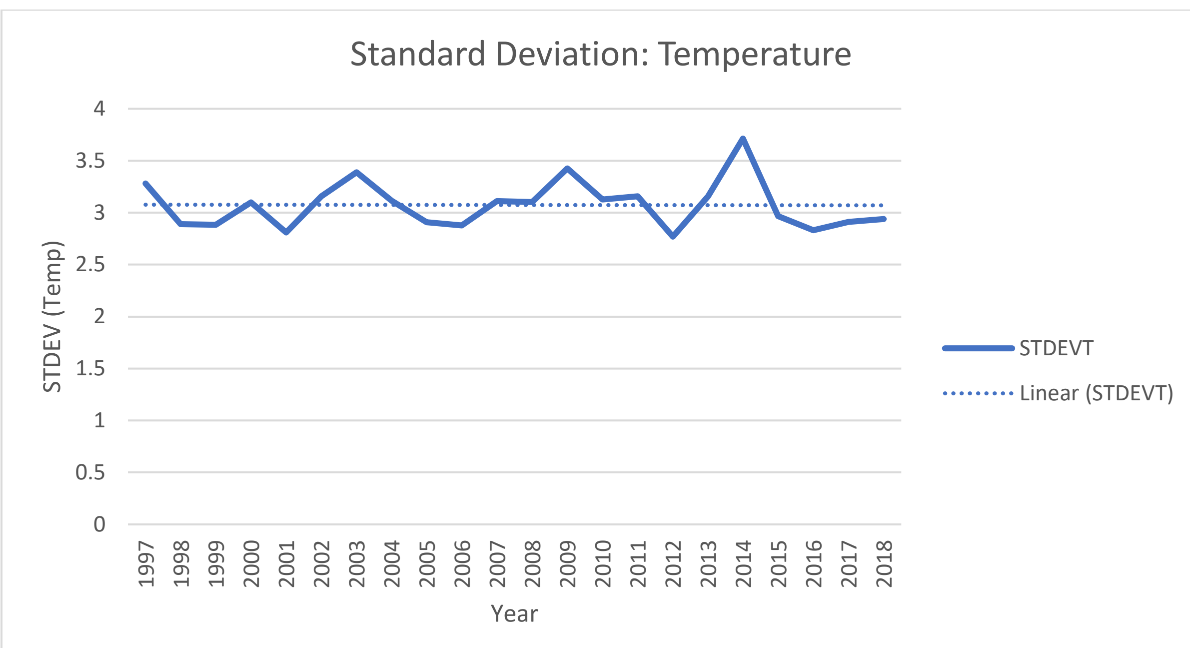


Graph 5 Yearly Rainfall Totals. Each line represents the respective utility average rainfall totals.

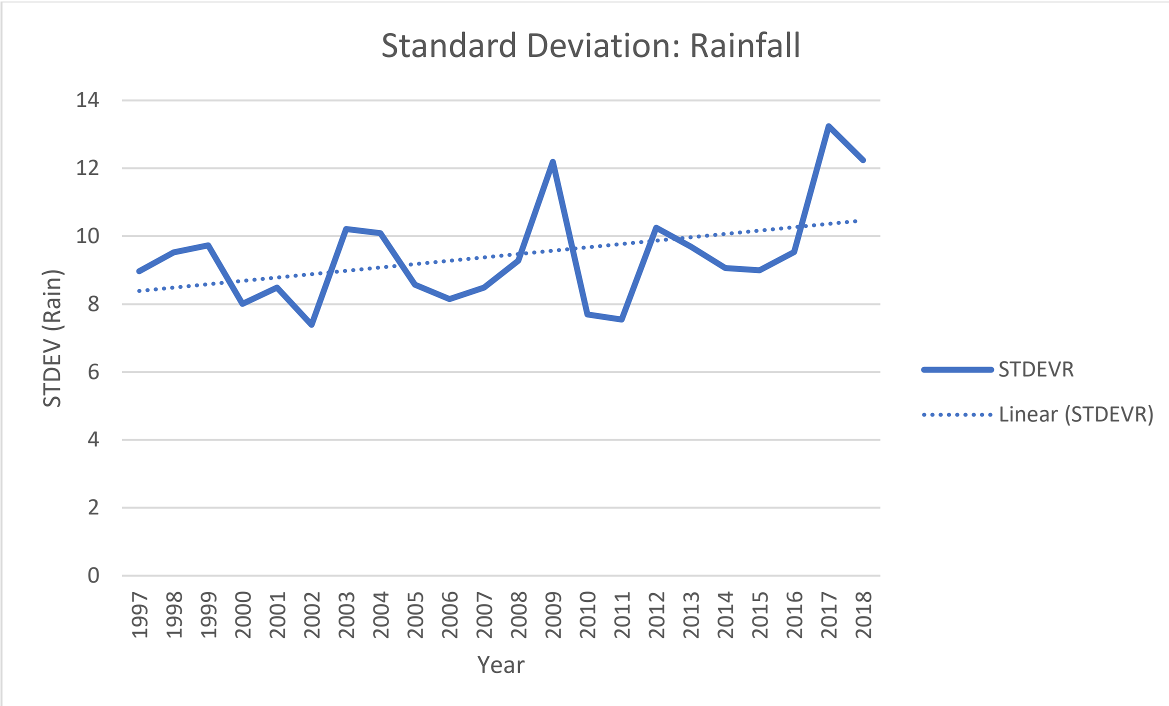


Graph 6 Yearly Average Wind Speed. Each line represents the respective utility average wind speed.

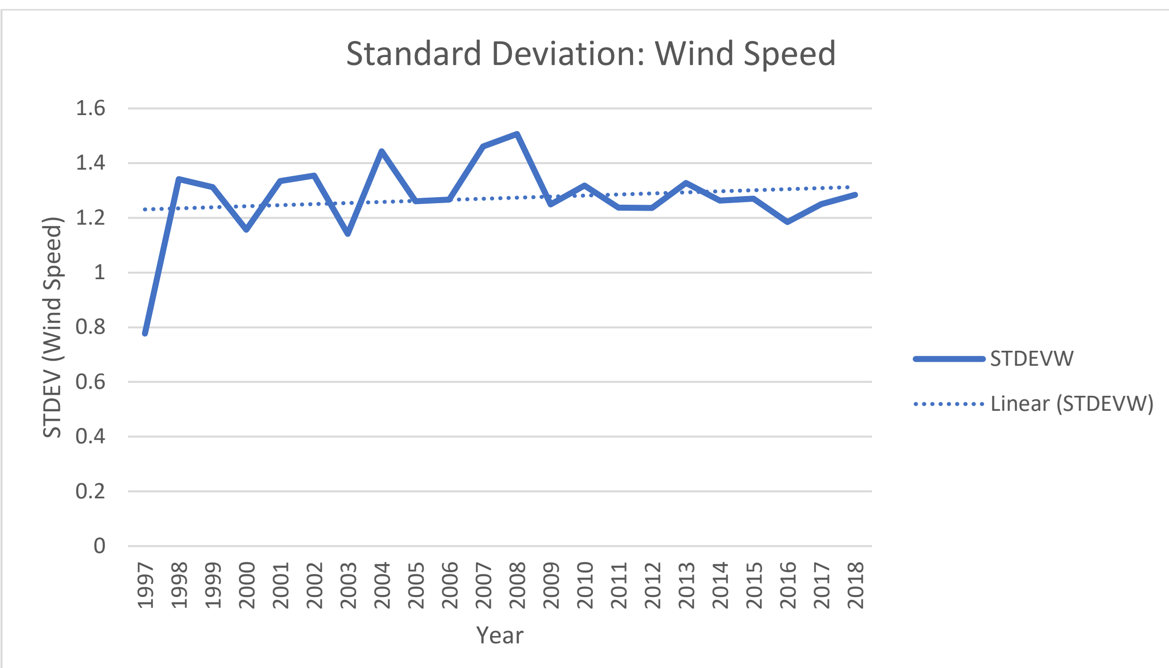
Graphs 7, 8, and 9 each represent the standard deviation of the respected variables across the state.



Graph 7 Standard deviation of temperatures (F) across state.



Graph 8 Standard deviation of rainfall (inches) across state.



Graph 9 Standard deviation of wind speed (mph) across state.

The following Pearson's Correlation tables were ran after testing for linearity in the data.

Correlations

		State Outages 10k	State Temp	State Rain	State Wind
State Outages 10k	Pearson Correlation	1	.168	.403	-.477*
	Sig. (1-tailed)		.268	.061	.031
	N	16	16	16	16
State Temp	Pearson Correlation	.168	1	.303	.189
	Sig. (1-tailed)	.268		.085	.200
	N	16	22	22	22
State Rain	Pearson Correlation	.403	.303	1	.099
	Sig. (1-tailed)	.061	.085		.331
	N	16	22	22	22
State Wind	Pearson Correlation	-.477*	.189	.099	1
	Sig. (1-tailed)	.031	.200	.331	
	N	16	22	22	22

*. Correlation is significant at the 0.05 level (1-tailed).

Correlations

		State Outages 10k	State Temp	State Rain	State Wind
State Outages 10k	Pearson Correlation	1	.168	.403	-.477*
	Sig. (1-tailed)		.268	.061	.031
	N	16	16	16	16
State Temp	Pearson Correlation	.168	1	.303	.189
	Sig. (1-tailed)	.268		.085	.200
	N	16	22	22	22
State Rain	Pearson Correlation	.403	.303	1	.099
	Sig. (1-tailed)	.061	.085		.331
	N	16	22	22	22
State Wind	Pearson Correlation	-.477*	.189	.099	1
	Sig. (1-tailed)	.031	.200	.331	
	N	16	22	22	22

*. Correlation is significant at the 0.05 level (1-tailed).

Table 1 State outages per 10k customers compared to state average temperature, rainfall totals, and average wind speed.

Table 1 takes the state wide number of outages per 10,000 customers and compares it to the state wide averages in temperature, rainfall, and wind speed. This is to show state wide trends in the data and to determine if there are any statistically significant indicators that climate change might be driving the number of vegetation caused power outages.

Correlations

		Duke Outages 10I	Duke Temp	Duke Rain	Duke Wind
Duke Outages 10I	Pearson Correlation	1	-.040	.245	-.661**
	Sig. (1-tailed)		.441	.180	.003
	N	16	16	16	16
Duke Temp	Pearson Correlation	-.040	1	.321	.168
	Sig. (1-tailed)	.441		.072	.227
	N	16	22	22	22
Duke Rain	Pearson Correlation	.245	.321	1	.134
	Sig. (1-tailed)	.180	.072		.276
	N	16	22	22	22
Duke Wind	Pearson Correlation	-.661**	.168	.134	1
	Sig. (1-tailed)	.003	.227	.276	
	N	16	22	22	22

**. Correlation is significant at the 0.01 level (1-tailed).

Table 2 Duke outages per 10k customers compared to Duke territory average temperature, rainfall, and wind speed.

Table 2 takes the average number of outages per 10,000 customers within Duke territory and compares it to the average temperature, rainfall, and wind speed across the territory. This is to show any trends across the territory that might be an indication that climate change is driving the number of vegetation caused power outages. By breaking down by territory, we can capture more localized data that might indicate a trend that may not be captured with state wide data.

Correlations

		FPL Outages 10k	FPL Temp	FPL Rain	FPL Wind
FPL Outages 10k	Pearson Correlation	1	.248	.343	-.385
	Sig. (1-tailed)		.178	.097	.071
	N	16	16	16	16
FPL Temp	Pearson Correlation	.248	1	.375*	.108
	Sig. (1-tailed)	.178		.043	.316
	N	16	22	22	22
FPL Rain	Pearson Correlation	.343	.375*	1	.031
	Sig. (1-tailed)	.097	.043		.445
	N	16	22	22	22
FPL Wind	Pearson Correlation	-.385	.108	.031	1
	Sig. (1-tailed)	.071	.316	.445	
	N	16	22	22	22

*. Correlation is significant at the 0.05 level (1-tailed).

Table 3 FPL outages per 10k customers compared to FPL territory average temperature, rainfall, and wind speed.

Table 3 takes the average number of outages per 10,000 customers within FPL territory and compares it to the average temperature, rainfall, and wind speed across the territory. This is to show any trends across the territory that might be an indication that climate change is driving the number of vegetation caused power outages. By breaking down by territory, we can capture more localized data that might indicate a trend that may not be captured with state wide data.

Correlations

		FPUC Outages 10k	FPUC Temp	FPUC Rain	FPUC Wind
FPUC Outages 10k	Pearson Correlation	1	.707*	.277	-.311
	Sig. (1-tailed)		.017	.180	.176
	N	16	9	13	11
FPUC Temp	Pearson Correlation	.707*	1	-.166	.411
	Sig. (1-tailed)	.017		.335	.119
	N	9	10	9	10
FPUC Rain	Pearson Correlation	.277	-.166	1	-.445
	Sig. (1-tailed)	.180	.335		.055
	N	13	9	17	14
FPUC Wind	Pearson Correlation	-.311	.411	-.445	1
	Sig. (1-tailed)	.176	.119	.055	
	N	11	10	14	15

*. Correlation is significant at the 0.05 level (1-tailed).

Table 4 FPUC outages per 10k customers compared to FPUC territory average temperature, rainfall, and wind speed.

Table 4 takes the average number of outages per 10,000 customers within FPUC territory and compares it to the average temperature, rainfall, and wind speed across the territory. This is to show any trends across the territory that might be an indication that climate change is driving the number of vegetation caused power outages. By breaking down by territory, we can capture more localized data that might indicate a trend that may not be captured with state wide data.

Correlations

		GULF Outages 10k	Gulf Temp	Gulf Rain	Gulf Wind
GULF Outages 10k	Pearson Correlation	1	.670**	.277	-.310
	Sig. (1-tailed)		.002	.149	.121
	N	16	16	16	16
Gulf Temp	Pearson Correlation	.670**	1	-.025	.038
	Sig. (1-tailed)	.002		.456	.435
	N	16	22	22	21
Gulf Rain	Pearson Correlation	.277	-.025	1	.096
	Sig. (1-tailed)	.149	.456		.340
	N	16	22	22	21
Gulf Wind	Pearson Correlation	-.310	.038	.096	1
	Sig. (1-tailed)	.121	.435	.340	
	N	16	21	21	21

**. Correlation is significant at the 0.01 level (1-tailed).

Table 5 Gulf outages per 10k customers compared to Gulf territory average temperature, rainfall, and wind speed.

Table 5 takes the average number of outages per 10,000 customers within Gulf territory and compares it to the average temperature, rainfall, and wind speed across the territory. This is to show any trends across the territory that might be an indication that climate change is driving the number of vegetation caused power outages. By breaking down by territory, we can capture more localized data that might indicate a trend that may not be captured with state wide data.

Correlations

		TECO Outages 10k	TECO Temp	TECO Rain	TECO Wind
TECO Outages 10k	Pearson Correlation	1	.011	.234	-.020
	Sig. (1-tailed)		.483	.192	.471
	N	16	16	16	16
TECO Temp	Pearson Correlation	.011	1	.169	-.129
	Sig. (1-tailed)	.483		.226	.283
	N	16	22	22	22
TECO Rain	Pearson Correlation	.234	.169	1	-.399*
	Sig. (1-tailed)	.192	.226		.033
	N	16	22	22	22
TECO Wind	Pearson Correlation	-.020	-.129	-.399*	1
	Sig. (1-tailed)	.471	.283	.033	
	N	16	22	22	22

*. Correlation is significant at the 0.05 level (1-tailed).

Table 6 TECO outages per 10k customers compared to TECO territory average temperature, rainfall, and wind speed.

Table 6 takes the average number of outages per 10,000 customers within TECO territory and compares it to the average temperature, rainfall, and wind speed across the territory. This is to show any trends across the territory that might be an indication that climate change is driving the number of vegetation caused power outages. By breaking down by territory, we can capture more localized data that might indicate a trend that may not be captured with state wide data.

The next table shows if the number of outages correlates with changes in standard deviation in temperature, rainfall, and wind speeds across the state.

Correlations

		State Outages 10k	STD Temp	STD Rain	STD Wind
State Outages 10k	Pearson Correlation	1	.339	-.068	-.215
	Sig. (1-tailed)		.099	.401	.211
	N	16	16	16	16
STD Temp	Pearson Correlation	.339	1	.150	-.328
	Sig. (1-tailed)	.099		.252	.068
	N	16	22	22	22
STD Rain	Pearson Correlation	-.068	.150	1	-.273
	Sig. (1-tailed)	.401	.252		.109
	N	16	22	22	22
STD Wind	Pearson Correlation	-.215	-.328	-.273	1
	Sig. (1-tailed)	.211	.068	.109	
	N	16	22	22	22

Table 7 State Outages compared to standard deviation of average temperature, rainfall, and wind speed.

Table 7 takes the number of outages for the entire state and compares it to the standard deviation of temperature, rainfall and wind speed amongst each of the utility's territorial averages. This is to determine if there is any statistical significance between climate variability and the number of vegetation caused power outages.

The following table is the collinearity diagnostics results from the regression analysis.

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	State Temp	State Rain	State Wind
1	1	3.992	1.000	.00	.00	.00	.00
	2	.007	23.279	.00	.00	.98	.01
	3	.001	69.545	.03	.03	.00	.98
	4	7.771E-5	226.648	.97	.97	.02	.00

a. Dependent Variable: State Outages 10k

Table 8 Collinearity diagnostics from regression test

Discussion

As it stands, the null hypothesis that climate change does not have an impact on the number of vegetation-caused power outages is true. This is due to the results which were generally statistically inconclusive to showing any evidence that some of the more long-term impacts of climate change are leading to a rise in the number of vegetation caused outages. This is further supported since the data used was not suitable for this research. This does not mean the experiment was a failure. There are flaws in the data need to be addressed before repeating, however valuable insight was gained into what those flaws are, and potential ways they can be dealt with before readdressing the hypothesis.

Looking at the results first, temperatures are trending warmer (graph 4) but variability has remained relatively stable (graph 7). This is line with the FSU 2008 study into the impacts of climate change on the Southeast USA. In terms of rainfall, both totals (graph 5) and variability (graph 8) have increased over the period of this study, which is also supported with the FSU 2008 study. Wind speed has shown a slight downwards trend (graph 6), but variability has increased slightly (graph 9). Graph 3 also shows a rise in the number of vegetation caused power outages per 10,000 customers. When it comes to correlations, there was an interesting bit found in the wind data. For state wide data, as the average wind speed increased, the number of outages decreased (table 1). The collinearity diagnostics found in table 8 also show a strong relationship between wind and the number of outages. Seeing an increase in average wind speed would likely indicate an increase in the number of storms or storm severity (Cloutier-Brisbee et al., 2019). It was expected to find that as wind speed increased, so did the number of outages, yet the data does not support this. However, there may be a simple explanation for this. Utilities may be coding a vegetation caused power outage event during a storm as a storm related event, causing it to show up under that category instead. This highlights some of the issues that can be found in the data itself and would be worth looking into in a future study. What are the issues, any why are they important?

The first major issue that needs to be addressed is the spatial data. Data collected from the Florida Public Service Commission only listed the number of outages by electric utility for their entire territory. Weather conditions can vary significantly from the northern part of the state down towards the bottom of the state. This can be seen in graph 4, which shows Gulf and Duke having cooler overall temperatures compared to FPL and TECO. Gulf and Duke both have more territory in the upper half of the state while TECO has territory along the west to southwestern portions of the state and FPL covering all the way from Miami at the bottom and up towards Jacksonville near the top (Image 2). Rainfall can change between the northern portions and southern portions and temperature can follow the same pattern (Lam, 2014). When it comes to wind speed, the best indication for predictors would have been localized wind speeds. As reported by Katz and Brown (1992), variability is more important than averages when it comes to climate change. Graph 6 demonstrates the average wind speed but does not give any indication as to the variability of the wind speed at a local level which is a more important factor. Essentially, the average wind speed data is useless for this project as it does not indicate the extremes. Variability might be difficult to address since wind monitoring stations are not as prevalent as temperature and rainfall, and things such as high wind events can be extremely localized. Additionally, average wind speed probably does not have much of an impact on trees compared to the maximum wind. Maximum wind speed could have been a better indicator since it would have the greatest impact on potentially damaging a tree. Averages showed wind speeds around seven miles per hour which are unlikely to damage any structurally sound tree.

Temperature, rainfall, and wind speed had to be averaged out across each of the utilities territory in order to address the issue surrounding the way outages were reported to the FPSC. Once again, we run into the same issue with trying to address variability. While we are on average seeing warmer temperatures across the globe, we still experience record lows followed by record highs due to wilder swings in temperature variability (Fischer & Schär, 2009). State and territory averages do not accurately reflect these changes variability of the climate in which trees are extremely sensitive to (Carrer, 2011). As stated earlier, having the wide spread in territory from northern to southern portions of the state as seen by Duke and FPL limit the ability to detect variability. In FPL territory for example, the more northern parts of the state can experience freezing conditions while the southern portions effectively never experience such weather. However, averaging out the data for the entire territory removes the ability to "see" these changes, which can matter when it comes to extreme events and trees contacting electrical lines and causing an outage.

The question begs then, what can be done to help establish more conclusive results? The lack of spatial data can be addressed since each of the utilities should already have this data on hand. After all, they need to collect the data somehow in order to report it to the FPSC. If for some reason any of the utilities do not have this data, it would be extremely valuable not just from this experiments point of view, but for any analysis involved in general vegetation management. It would enable that utility to track any troublesome hotspot that might be regularly impacting their facilities. However, it is almost certain that any of the utilities discussed in this project should have the data available. This data will help address the localization issues significantly that this experiment faced. While reporting weather conditions at every single exact location may not be possible, simply knowing where the locations are themselves can help with matching each outage up to the nearest weather reporting station to assist in gathering data. This can be readily done in any geographic information systems technology that a utility has, such as ArcGIS. Coupled with weather data through NOAA, we can gather insights into the more extreme events and track changes on a smaller scale, such as at a monthly level instead of a yearly level. By collecting this data, it should allow for statistically significant results. As mentioned in (Kirschbaum et al., 1996), forests and trees in general will be impacted by climate change. It would come as a surprise if data came back showing that there was no relation between the number of vegetation caused outages and climate change. Even from the data in this experiment, with FPUC and Gulf, two of the smaller utilities, there was statistically significant ($p<.05$) evidence that temperature played a moderate role in the number of vegetation caused power outages (tables 4 & 5). This could be due to outliers in the data, or it could show that the geographically smaller areas are able to accurately determine correlation better than areas that cover a large region. However, having access to more granular data would allow for a better check of the local conditions and to determine if the data from FPUC and Gulf is indeed reflective of a common trend, or just an outlier.

Another flaw in the data can potentially be found in how the data was initially recorded by the utilities themselves. While it is likely that the number of vegetation caused power outages is mostly accurate, there is still room for error in the reporting of the data. Major outages will be investigated by a utility arborist for cause. Large and small outages can also be reported by the grid itself through smart technology. Finally, it is also possible that the ones deeming if an outage was vegetation or not are linemen themselves, who may make mistakes when deeming if the outage is vegetation caused or not. While out working in stormy conditions, it might be hard to identify exactly what caused an outage, since it could be any number of possible debris moving around. It would be helpful for utilities to report on their data with an estimated margin of error. This will allow us to determine how accurate their numbers are, and to determine if the data is still usable for something that might be only playing a small role in the changes to the number of vegetation caused power outages. There is also the possibility that vegetation caused power outages during a storm event are being reported as storm caused, not vegetation caused. Evidence for this shows in the wind data, which showed a moderate negative correlation between the number of outages and average wind speed (table 7). Periods of stronger storms are likely to increase the average wind speed, and it is expected to find that during those high wind events, there would be an increase in the number of vegetation caused power outages.

Other factors could be at play that might be interfering with the data. One thing that could be checked with better data from utilities would be the amount of overhead electrical lines added per year. By simply increasing the number of line miles, it opens up more locations for trees to make contact with electrical lines. In the experiment, some of this was mitigated by changing the data to reflect outages per 10,000 customers. However, a flaw in this method is that we do not know where the customers are, and it doesn't reflect line construction differences in rural compared to urbanized areas. An urbanized area is more likely to get serviced by underground utilities or can be serviced by existing overhead lines. Additional lines may be smaller, and urbanized locations will not have the same makeup as forests. The use of cities planning tree placement and a denser population that would warrant the use of more reliability trimming, there is a smaller chance of electrical lines being impacted. In rural areas, it is more cost effective to place overhead lines than underground lines simply due to upfront costs (Fenrick & Getachew, 2012). Many miles of lines might be run along a road next to a forest, which provides plenty of opportunities for a tree come in contact with an electrical line during an extreme weather event.

Utilities often maintain the vegetation along their power lines in multi-year cycles. These cycles can range depending on if the line is connected to something such as a hospital, or if it is a line feeding several customers in a rural location. More time would be spent trimming lines near critical infrastructure than other locations, meaning it should be rare that a tree contacts power lines in these locations. Rural locations may experience more vegetation caused power outages since utilities do not see the value of trimming for reliability for a couple of customers when they can trim for reliability for several thousand. It is not to say that a utility does not value its rural customers, just that from a financial point of view it does not make sense to trim those lines as often as tree trimming is generally very expensive. Getting costs from each utility is difficult due to individual contracts and what kinds of trees might be in a region that a tree trimming contractor might service. Items such as height, canopy size, species, and the tree's location itself can all play a role in cost. Utilities should generally pay a bulk rate for service so cost isn't typically broken down by tree, but instead may be broken down by span (from one pole to the next) or by mile. Trimming also isn't done at a steady rate throughout the year. There are many obstacles that can slow a crew down such as the weather, and the crew to miss sections that are due for trimming. Now that there are fewer trees trimmed along a power line, it allows for a greater chance of trees to make contact with the lines in the first place due to inadequate or a lack of trimming. This is something that is not addressed in the data. How many of the outages could have been prevented if tree trimming was done to reach end of year goals the year prior? Now this is data that utilities would unlikely be willing to publicly release as it could open them up to all sorts of liability issues and public scrutiny, however this is still something they could check themselves internally. However, it would help significantly with trying to address if a rising number of vegetation caused outages could be explained by another phenomenon.

Further Research

What are the options for a future rerun of this experiment? First, there needs to be a drastic improvement in the data used for this research as already covered. This data can either be made publicly or kept internally by the utilities. Making the data publicly available would allow outside researchers access to determine if there are any patterns found across all the utilities across the state. However, it also opens utilities to potential criticism regarding trimming practices if customers find outage hotspots that do not appear to be getting addressed. This leaves another option, and that's for utilities to keep the data internally and run the tests themselves. They would have access to all the internal data such as exactly where the outage occurred, which could be placed into a geodatabase. Such a geodatabase can also collect live weather data from various stations or other sources along with historic data, and when an outage occurs, data could be saved with the outage indicating approximately what the conditions were at the site. Temperature and rainfall totals may become more accurate at that site, items such as a gust of wind toppling a tree over may not be an exact measurement. However, the data becomes immensely more useful as they would have a better idea as to the approximate windspeeds. From this data, they can extrapolate information such as if the location has been experiencing larger swings in temperature, rainfall, or windspeeds compared to the average conditions around the site. Having this data can also mean utilities can check things such as last trim dates around the outage site, which they can use to determine if the outage could have been prevented if it was outside the routine trimming cycle. They can also use this data to determine if the time between trimming should be decreased since they are seeing more vegetation caused outages than they used to. This could also be the first step towards indicating if climate change is playing a role in the number of vegetation caused outages. Changes in frequency in the number of outages could show that the area is experiencing longer growing seasons due to warmer temperatures (Chung et al., 2013). Historic weather data for sites can be used to determine if there has been a large standard deviation away from the average conditions for that season or year, which may also indicate that variability from climate change is also driving the number of outages. There are several ways a utility can begin checking their data to determine if climate change is playing a role in the number of vegetation caused outages. First, it might be smart to check in areas that are experiencing an increasing number of outages. They should then look at two things, has there been an increase in the amount of overhead power lines in the area? If there has been, it could potentially address the issue that there are simply more opportunities for trees to make contact with those lines and cause an outage. If there has not been, or the area where the new lines have been installed are not around any trees, they can move on to the next step. If there has been an increase in line miles and an increase in vegetation caused power outages, the utility can look at their data and determine where the outages are occurring exactly. If they are not occurring on the new lines and are occurring on the old lines, they can move on with their investigation. If they are occurring on new lines, it should be taken into consideration that adding those additional miles could open up the ability for more trees to impact the lines before moving on. In any of those cases, the utility still has the opportunity to further investigate the role climate change might be playing on the number of outages. The next step in the process would be to gather all the historic weather data for that area and determine what the mean temperature, rainfall, and wind speed is in the area. They can break this down either by year or all the way down by month if they want. Next would be to look at the more recent weather data and determine how far off the conditions are from the standard deviation of the average conditions. Since large swings in the standard deviation would indicate more extreme conditions, which are expected to rise with climate change (Cloutier-Brisbee et al., 2019), it would be a strong indicator that climate change is impacting the number of vegetation caused power outages. Things utilities should look out for are a warmer than normal winter (which would support an extended growing season), signs of drought, or signs of flooding. Swings in wind speed would indicate a storm, however storm frequency would need to be considered first before drawing conclusions that the storm and extreme wind event is driven by climate change. However, by having localized data, utilities can begin this process by looking at how often storms impact the area. If they are becoming more frequent or severe, this is also an indicator that climate change is a driving force behind a rising number of outages (Jordaan, 2018).

Why would a utility want to look for this data in the first place? First, anytime the electricity is down for the consumer, the utility is not making money. This cuts into their profits, and as a publicly held company, they have a responsibility to their shareholders. Second, any time trees do make contact with a wire, it cost money to make any necessary repairs to the facilities. This can vary drastically depending on how large the tree is, or what kind of damage was done. This can be equally as expensive. As an electric utility, they have the responsibility of providing power to everyone. When the power is out, it can potentially cost lives for those who require specialized medical equipment or in the case of Florida, air conditioning to survive the heat. If climate change is determined to be impacting the number of outages, the utilities can then use that information to better prepare their facilities. The data shows a trend towards warmer weather, meaning a longer growing season. A utility could mitigate this by investing more money into placing lines underground or investing more in reliability trimming and shortening the cycles in which the trees along the line are maintained at. Since both can be expensive, utilities can then use the data to determine which areas are being impacted the most and are experiencing the largest rise in the number of outages. Resources can be prioritized in those locations first before moving on to locations that are not being impacted as severely. By addressing the issue ahead of time, this can save a utility money from having to constantly fix current structures. It also enables them to improve reliability, which at the end of the day means the utility would earn more money. Research also showed an increase in storm frequency and intensity, putting trees at higher risk of being damaged through high winds. While it can be difficult to prevent tree debris from causing an outage during a high wind event, cutting trees back further along the right away should reduce the impacts.

In conclusion, the results came back inconclusive for showing any linkage between the impacts of climate change and the number of vegetation caused power outages. This is primarily driven by the poor quality publicly available data and is an issue that needs to seriously be readdressed before reattempting the experiment. There is already evidence into how climate change will impact forests and tree growth, and this information alone should be enough for utilities to begin considering what kinds of impacts that will have on their lines. Data should either become publicly available, or utilities should invest time and resources into investigating the link themselves. By determining if there is indeed a link or not, utilities can then make the necessary arrangements to help mitigate future impacts. While the cost for adapting may be expensive up front, the sooner they can begin adjusting their systems, the more money they will save long term. Improvements to the facilities would improve reliability and lower the cost of maintenance by either moving lines underground or increasing the distance that trees must be from the lines. Overall, it points to simply needing more higher quality data in order to accurately determine if there is indeed a link between the number of vegetation caused power outages and climate change.

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